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TOXIC FACTORS IN ACID SOILS of the Southeastern United States as Related to the Response of Alfalfa to Lime

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TOXIC FACTORS IN ACID SOILS of the Southeastern United States as Related to the Response of Alfalfa to Lime

By C. D. Foy, *soil scientist, Soil and Water Conservation Research Division, Agricultural Research Service*[1]

The reasons for poor growth of plants on acid soils are not well understood. At a given soil pH value the cause seems to vary with soil type and also with plant species or variety. Possible limiting factors that have been suggested are limited availabilities of calcium (*2, 3, 4, 5*),[2] molybdenum (*12, 13, 17*), and phosphorus (*14*), and toxicities of hydrogen (*6, 9, 29*), aluminum (*19, 21, 23, 25, 29, 31*), manganese (*1, 7, 22, 26*), and iron (*24*).

Acid soils in the Southeastern United States with equal pH values differ widely in their lime requirements for maximum yield of a given crop. This investigation attempts to identify the factors that limit plant growth in such soils and to relate levels of these factors to lime response of alfalfa. Such a study should provide a basis for more precise liming recommendations.

The work reported in this bulletin was conducted in cooperation with the Arkansas Agricultural Experiment Station at Fayetteville during 1958 and 1959. It was initiated specifically to provide support for field studies of the Southern Regional Lime Project, a cooperative undertaking between the Soil and Water Conservation Research Division of the Agricultural Research Service, USDA, and various Southeastern State agricultural experiment stations.

PROCEDURE

The general procedure was to determine the lime response of alfalfa for 17 acid soils collected from 5 Southeastern States, and to relate this response to soil properties and plant symptoms and composition. In a separate experiment the effects of high phosphorus, peat, sand, and calcium chloride treatments were compared with those of lime on four

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[1] The author is indebted to Leslie Hileman and Lyell Thompson, Soil Testing Laboratory, Arkansas Agricultural Experiment Station, for determination of exchangeable cations, organic matter, phosphorous levels, and lime requirements of soils; A. W. Specht and J. W. Resnicky, U.S. Soils Laboratory, Soil and Water Conservation Research Division, for analysis of some plant samples; and to E. J. Koch, Biometrical Services, Agricultural Research Service, for statistical assistance.

[2] Italic numbers in parentheses refer to Literature Cited, p. 16.

of the soils. The soils studied are described in tables 1 and 2. Chemical characterization of soils was as follows: Available phosphorus was extracted according to Bray and Kurtz (*8*) and measured colorimetrically by the molybdophosphoric acid blue color method (*15*, *p. 159*). Cation-exchange-capacity (CEC) was determined by the ammonium acetate method (*15*, *p. 66*). Easily oxidizable organic matter was determined by the Walkley-Black method (*15*, *p. 219*). Exchangeable cations were extracted with 1*N* ammonium acetate at pH 7.0 Exchangeable K, Na, and Ca were determined by flame photometer and Mg with Titan yellow (*28*). Soil pH was determined on a 1:1 soil-water suspension. Lime requirement was estimated by the Woodruff method (*30*).

TABLE 1.—*General description of soils used in liming experiments, Fayetteville, Ark., 1958–59*

Experiment and soil type	Physiographic region and SCS problem area [1]	Sample site
Experiments 1a and 1b:		
Calloway silt loam (formerly Olivier).	Atlantic and Gulf Coastal Plain (Loess Hills and Terraces).	Wynne, Ark.
Dundee silty clay loam	Atlantic and Gulf Coastal Plain (Southern Alluvial Plains).	Earle, Ark.
Loring silt loam 1	Atlantic and Gulf Coastal Plain (Loess Hills and Terraces).	Colt, Ark.
Loring silt loam 2 (formerly Richland).	do	Marianna, Ark.
Zanesville silt loam (formerly Centerton).	Appalachian-Ozark Highlands (Northern Ozarks).	Fayetteville, Ark.
Experiment 2:		
Cecil sandy loam	Appalachian-Ozark Highlands (Piedmont Plateau).	Watkinsville, Ga.
Johnsburg silt loam	Appalachian-Ozark Highlands (Northern Ozarks).	Fayetteville, Ark.
Lakeland loamy sand	Atlantic and Gulf Coastal Plain (Middle and Upper Coastal Plain).	Live Oak, Fla.
Taloka-Parsons-Johnsburg silt loam (formerly Cherokee).	Appalachian-Ozark Highlands (Northern Ozarks).	Fayetteville, Ark.
Waynesboro sandy loam (formerly Hanceville).	do	Do.
Experiment 3:		
Bayboro clay loam	Atlantic and Gulf Coastal Plain (Flatwoods of Coastal Plain).	Fleming, Ga.
Bladen clay loam	do	Do.
Leon fine sand	do	Do.
Vaiden clay loam	Atlantic and Gulf Coastal Plain (Blacklands of Coastal Plain).	Brooksville, Miss.
Experiment 4:		
Decatur clay loam	Appalachian-Ozark Highlands (Appalachian Valleys and Ridges).	Belle Mina, Ala.
Rains sandy loam	Atlantic and Gulf Coastal Plain (Middle and Upper Coastal Plain).	Tifton, Ga.
Tifton sandy loam	do	Do.

[1] Problem Areas in Soil Conservation, USDA, Soil Conservation Service Map, Beltsville, Md., July 1950.

TABLE 2.—*Chemical characteristics of soils before treatment at Fayetteville, Ark.*

Experiment and soil	pH value	Lime requirement [1]	Cation exchange capacity	Exchangeable cations			Available P	Organic matter
				Ca	Mg	K		
		Tons/acre	*Meq./100 g.*	*Lb./acre*	*Lb./acre*	*Lb./acre*	*Lb./acre*	*Percent*
Experiment 1a:								
Calloway	5.4	1	7.6	1,100	225	220	113	0.6
Dundee	4.8	2	19.7	2,500	250	460	140	1.0
Loring 1	5.3	2	12.9	1,600	250	240	87	.3
Loring 2	5.1	1	5.0	700	100	280	140	.7
Zanesville	4.9	1.5	5.5	900	75	100	44	1.0
Experiment 1b:								
Dundee	5.0		20.2	2,400	250	240	105	1.2
Loring 1	5.3		7.0	1,400	250	160	70	.6
Loring 2	5.3		4.9	600	175	160	26	.5
Zanesville	5.0		6.9	1,100	75	100	26	1.6
Experiment 2:								
Cecil	5.2	1.5	5.3	500	100	100	79	1.5
Johnsburg	5.1	1.5	7.6	1,100	100	150	17	1.6
Lakeland	5.1	1.5	3.8	1,000	50	60	157	1.6
Taloka-Parsons-Johnsburg	5.2	1.5	7.3	1,200	100	40	13	1.3
Waynesboro	5.2	1.5	6.3	700	50	100	13	1.3
Experiment 3:								
Bayboro	5.0	4.0	30.1	1,100	250	290	17	4.0
Bladen	4.8	3.5	11.6	600	225	40	13	2.5
Leon	4.2	3.0	4.9	300	50	40	13	2.3
Vaiden	5.8	1.5	32.6	6,400	250	280	13	4.0
Experiment 4:								
Decatur	5.5	1.5	11.7	1,900	150	250	70	1.6
Rains	4.7	1.5	3.4	300	75	110	13	1.5
Tifton	5.6	1.0	4.0	500	75	210	113	1.6

[1] Woodruff method.

Due to limitation of greenhouse space, the soils were studied in groups as indicated in table 2. Five experiments were conducted in the greenhouse. Treatments in experiments 1a, 2, 3, and 4 were combinations of lime rates with either two or three replications in randomized blocks. Fertilization levels used in these experiments were intended to be adequate to remove obvious deficiencies of the major elements and to adjust different soils to somewhat comparable soil test levels, but not sufficient to mask the normal lime response. All soils received 25 pounds of N and 4.54 pounds of B per acre. In experiments 2, 3, and 4 each soil received 30 pounds of Mg per acre. Potassium was applied at 249 pounds of K per acre on all soils except Tifton and Decatur, which received 166 pounds. Phosphorus fertilization rate varied with different soils, depending upon the initial soil test value. Rates used were 44 pounds of P per acre on Tifton and Lakeland soils, 65 pounds on Decatur and Cecil, 98 pounds on Loring 1, Loring 2, and Calloway, 132 pounds on Waynesboro, Bladen, Leon, Bayboro, Vaiden, and Rains, 153 pounds on Johnsburg and on Taloka complex, 196 pounds on Dundee, and 295 pounds on Zanesville.

The lime used was reagent grade calcium carbonate. Phosphorus was supplied as monocalcium phosphate, potassium as potassium chloride, nitrogen as urea, magnesium as magnesium sulfate, and boron as boric acid. Fertilizers and lime were mixed with the entire soil

and allowed to incubate at approximately field moisture condition for 1 month before planting. Alfalfa (var. Buffalo) was planted in No. 10 cans lined with polyethylene bags, each containing 7 pounds of soil. Stands were thinned to 15 plants per can, and either two or three harvests were made at the early bloom stage.

At the end of the experiments aluminum was extracted from air-dry soils with NH_4OAc at pH 4.8 according to McLean and others (*20*) and with 1 *N* KCl at pH 7.0. Exchangeable manganese was extracted from air-dry soils with 1 *N* NH_4OAc at pH 7.0 and determined by the periodate method (*15, p. 393*). Samples from plant tops for experiments 2, 3, and 4 were analyzed spectrographically. Plant samples from experiment 1a were not analyzed.

Experiment 1b involved different batches of four of the same soils used in experiment 1a. It was designed to compare the effects of high phosphate, peat, sand, and calcium chloride with those of lime. Such materials have been reported to reduce the toxicities of some acid soils (*2, 4, 5, 10, 26*). Effects of these materials on plant yields, symptoms, and composition could furnish clues concerning specific causes of toxicity in acid soils. All pots in the experiment, including the check, received a basal fertilizer treatment of 25 pounds N, 87 pounds P, 249 pounds K, 30 pounds Mg, and 4.54 pounds of B per acre. The experimental treatments used in combination with the basal treatment included a no-treatment check, 4 tons of $CaCO_3$ per acre, 873 pounds of P per acre, 5 percent peat by weight (pH 5.5), 50 percent sand by weight, and $CaCl_2$ at one-fourth the calcium equivalent of the $CaCO_3$ treatment.

The entire tops of plants from experiment 1b were ground, and samples were wet-digested in a mixture of perchloric, nitric, and sulfuric acid (*15, p. 333*). Manganese was determined by periodate (*15, p. 102*) and aluminum by "aluminon" (*11*). Iron was determined by orthophenanthroline (*15, p. 389*) and phosphorus by the 1, 2, 4-aminonapthol-sulfonic acid-reduced molybdophosphoric blue color method (*15, p. 148*). Potassium, magnesium, and calcium were determined with a flame photometer.

RESULTS AND DISCUSSION

Yield Response of Alfalfa to Lime

Detailed results of the five experiments, including yields and soil and plant characteristics, are presented in the appendix, tables 5 to 12. Alfalfa yield responses to lime applications for selected soils are shown graphically in figures 1 to 4. In order to provide a basis for comparing lime response between soils, alfalfa yield for each soil is expressed as a percentage of the maximum yield attained with lime for that particular soil. Also, yields are plotted against soil pH, rather than amounts of $CaCO_3$ applied. The actual lime rates used are shown for each experiment in the appendix tables.

All soils listed in figures 1, 2, 3, and 4 show significant alfalfa yield increases with liming, but the shapes of the response curves are widely different. The response of alfalfa to lime on Zanesville was small, considering the low pH value of this soil (4.6) when unlimed (fig. 1). Taloka complex gave a similar type of response (appendix table 7). Both soils produced 75 to 80 percent of maximum yield for alfalfa without the addition of lime,

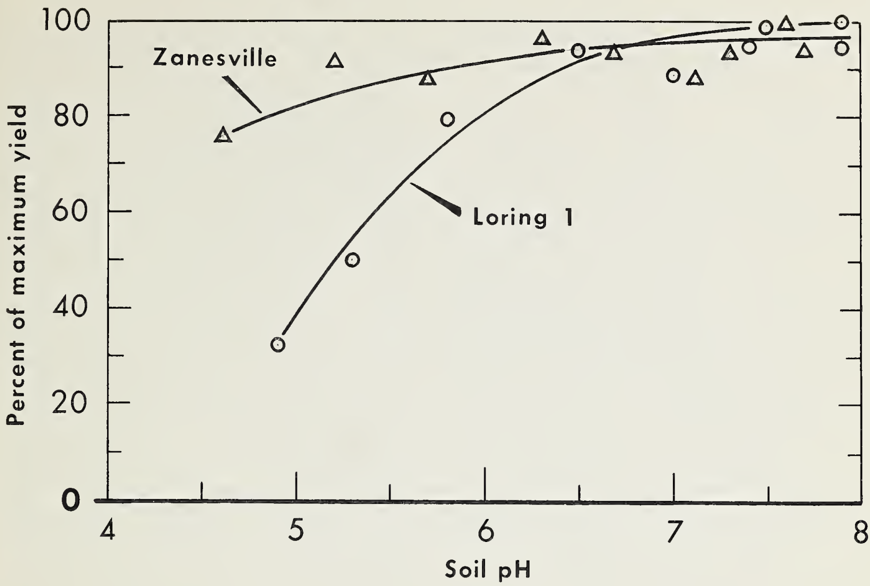

FIGURE 1.—Experiment 1: Alfalfa yield as affected by soil pH changes induced by liming.

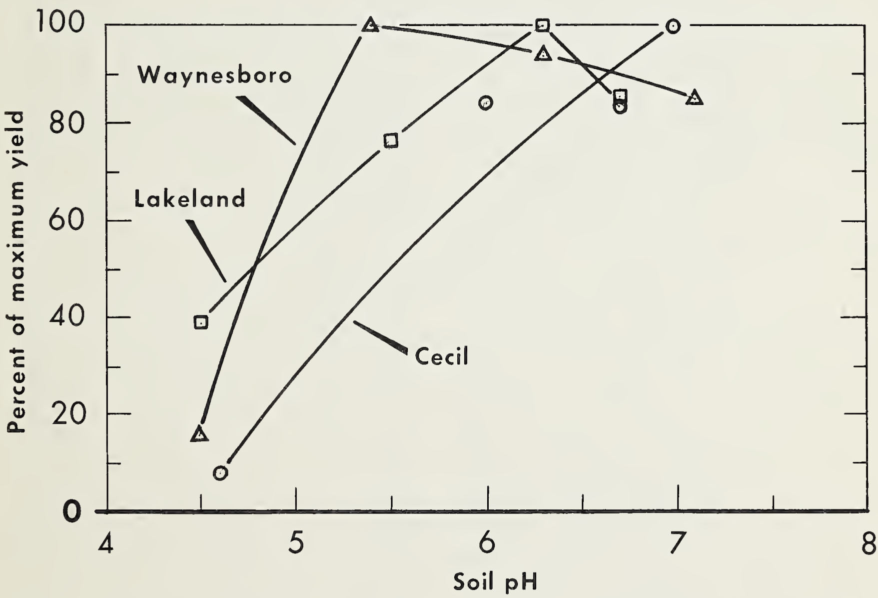

FIGURE 2.—Experiment 2: Alfalfa yield as affected by soil pH changes induced by liming.

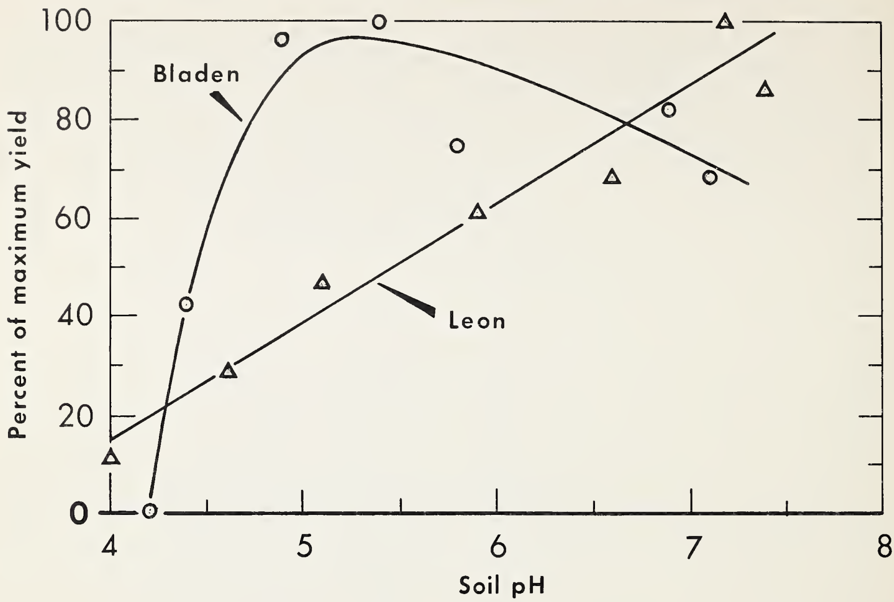

FIGURE 3.—Experiment 3: Alfalfa yield as affected by soil pH changes induced by liming.

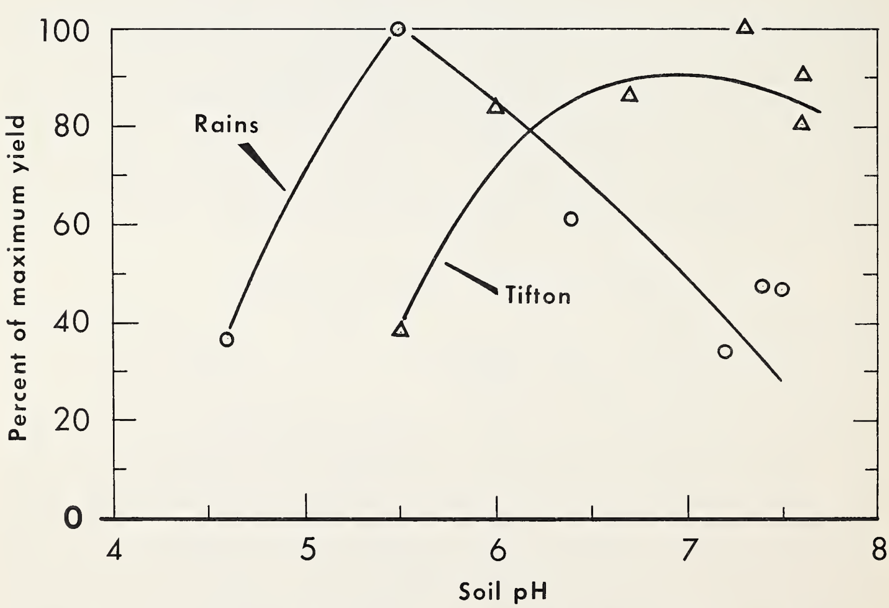

FIGURE 4.—Experiment 4: Alfalfa yield as affected by soil pH changes induced by liming.

and near-maximum yields when limed to pH 5.0 to 5.5. Johnsburg showed a somewhat similar type of response curve, but this soil type appeared to be more toxic to alfalfa than Zanesville and Taloka complex at the same pH level. Johnsburg and Taloka complex showed a tendency toward decreased yields when limed to a pH above 5.5. Loring 1 and Loring 2 soils, represented by Loring 1 in figure 1, were extremely toxic to alfalfa at pH values below 6.0, but both soils gave near-maximum yields at pH 6.5 to 7.0 and showed no tendency toward yield depression with further liming. Unlimed Dundee soil was less toxic than unlimed Loring 1 or Loring 2 at pH values below 5.0 but produced maximum yields when limed to pH 7.5 (appendix table 5). The lime response of alfalfa on Calloway was similar to that on Zanesville.

Alfalfa yields on Waynesboro soil reached a maximum at about pH 5.5 and tended to decline as the pH was increased to 7.0 (fig. 2). Yields on Lakeland reached a maximum at pH 6.0 to 6.5 and tended to decline with further liming. Yields on Cecil soil were increased almost linearly with pH increases to 7.0. This soil was extremely toxic, giving only 7 percent of maximum yield when unlimed at pH 4.6. Plants died by the time of the first harvest. Leon soil also gave a near linear alfalfa yield response to pH changes from 4.0 to 7.4 (fig. 3), but was somewhat less toxic than Cecil.

Figure 3 shows that Bladen was the most toxic soil in the entire group, giving practically no alfalfa growth when unlimed (seedlings died before reaching a height of 1 inch). Yields on Bladen were increased sharply by liming to a pH of 5.0 to 5.5, but tended to decrease with liming to pH 7.0. Yields on Rains soil were reduced even more sharply by liming above pH 5.5 (fig. 4). Yields on Tifton soil were increased by liming to pH 7.0 but tended to decrease with higher pH values.

Bayboro, Vaiden, and Decatur soils did not give significant yield responses to lime; however, yields on Decatur did show a consistent upward trend (appendix tables 9 and 11).

Comparative effects of lime, high phosphate, peat, sand, and $CaCl_2$ on alfalfa yields with Zanesville, Loring 2, Loring 1, and Dundee soils are shown in appendix table 6. Liming all four of these soils to pH 7.0, and above, significantly increased yields. The addition of 873 pounds of P per acre as monocalcium phosphate significantly increased yields on Zanesville, Loring 1, and Dundee soils, and the increase for Loring 2 was almost significant at the 5-percent level. At the first cutting this treatment produced higher yields than lime on all soils. The addition of 5 percent of peat by weight significantly increased yields on Loring 1 and Dundee soils, and the increase on Zanesville closely approached significance. Yields on Loring 2 soil were not affected by the peat treatment; however, on Loring 1 and Dundee soils peat was as effective as lime in increasing yields for three cuttings.

Dilution of acid soils by 50 percent with sand significantly increased alfalfa yields on Zanesville but not on the other three soils. The calcium chloride treatment greatly reduced yields on all soils. Yields on the unlimed soils varied widely, with Zanesville yielding only one-fourth as much as Loring 2, Loring 1, and Dundee. The sample of Zanesville soil used in this experiment gave a much larger yield response to lime than did the sample used in experiment 1a. This difference will be discussed under manganese toxicity.

Growth-Limiting Factors in Acid Soils

Manganese Toxicity

Alfalfa plants on unlimed Waynesboro, Cecil, Johnsburg, Loring 1, Zanesville, Dundee, Taloka complex, Loring 2, and Calloway soils showed, in varying degree, the symptoms illustrated in figure 5 for the Dundee soil. Symptoms started as a faint yellowing at leaf tips and around the margins, and gradually progressed inward toward the midrib. These were identical to the symptoms produced by excess manganese in sand culture studies conducted by the author, and similar to the symptoms that Schmehl and coworkers (*26*) obtained with alfalfa on acid Mardin silt loam and described as manganese toxicity.

The effects of lime on soil properties, plant yield, and plant composition on five soils representing this group are given in table 3. The most toxic soils are those containing the highest levels of exchangeable manganese. For example, the highly toxic Waynesboro and Cecil soils contained 138 and 99 parts per million exchangeable manganese, respectively, whereas the mildly toxic Zanesville contained only 48 parts per million at about the same pH. For this group of soils, lime response and decrease in plant symptoms were closely related to decreases in exchangeable manganese in soils and decreases in manganese contents of plants.

Lime responses on this group of soils were also accompanied by decreases in extractable aluminum; however, other evidence indicates that aluminum toxicity was not a factor in these soils. First, plant symptoms were entirely different from those of aluminum injury. Second, both plant symptoms and composition indicated that excess manganese was the primary toxic factor involved. Furthermore, wide yield differences between the unlimed soils are not explained by differences in extractable aluminum. For example, Cecil, the most toxic soil in the group, contained less extractable aluminum (in milliequivalents or percentage saturation) than Johnsburg or Zanesville, which yielded seven to eight times as much alfalfa as Cecil on unlimed soils.

FIGURE 5.—Effects of lime on manganese toxicity in alfalfa on Dundee silty clay loam: Left—no lime, pH 4.7; right—lime, pH 7.5.

TABLE 3.—*Response of alfalfa to liming on Waynesboro, Cecil, Johnsburg, Loring 1, and Zanesville soils as related to soil and plant composition, experiments 1a and 2, Fayetteville, Ark.*

Experiment and soil	$CaCO_3$	Soil pH	Alfalfa yield	Soil properties: Extractable Al, NH_4OAc pH 4.8	Soil properties: Extractable Al, KCl pH 7.0	Soil properties: Exchangeable Mn	Plant composition: Mn	Plant composition: Al	Plant composition: Fe	Plant composition: Ca	Plant composition: P
Experiment 2:	*Tons/acre*		*G./pot*	*Meq./100 g.*	*Meq./100 g.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*Pct.*	*Pct.*
Waynesboro	0	4. 5	1. 40	2. 11	0. 40	138	1, 970	150	160	1. 2	0. 20
	1	5. 4	9. 23	. 97	. 01	49	240	190	98	1. 7	. 24
	2	6. 3	8. 62	. 85	. 01	37	170	200	72	2. 0	. 24
	3	7. 1	7. 80	. 74	. 02	24	150	190	37	2. 0	. 22
Cecil	0	4. 6	. 74	1. 37	. 13	99	1, 430	240	170	2. 6	. 30
	1	6. 0	8. 04	. 89	. 01	50	320	190	250	1. 8	. 26
	2	6. 7	7. 96	. 90	. 02	32	190	160	200	1. 8	. 24
	3	7. 0	9. 58	1. 03	. 00	28	220	240	300	1. 9	. 24
Johnsburg	0	4. 4	5. 28	1. 75	. 55	80	1, 660	230	320	1. 3	. 22
	1	5. 0	8. 56	1. 11	. 05	38	460	180	260	1. 6	. 22
	2	5. 8	7. 59	. 90	. 01	31	240	190	250	1. 9	. 22
	3	6. 6	7. 44	. 73	. 01	24	160	200	250	2. 3	. 28
Experiment 1a:											
Loring 1	0	4. 9	3. 38	1. 74	----	59	-----	-----	-----	----	----
	. 5	5. 3	5. 26	1. 53	----	18	-----	-----	-----	----	----
	1. 0	5. 8	8. 41	1. 44	----	15	-----	-----	-----	----	----
	3. 0	7. 5	10.45	1. 26	----	5	-----	-----	-----	----	----
Zanesville	0	4. 6	8. 04	1. 29	----	48	-----	-----	-----	----	----
	. 5	5. 2	9. 73	. 87	----	26	-----	-----	-----	----	----
	1. 0	5. 7	9. 36	. 76	----	12	-----	-----	-----	----	----
	3. 0	7. 3	9. 91	. 61	----	8	-----	-----	-----	----	----

Results of experiment 1b (appendix table 6) provide additional support for the hypothesis of manganese toxicity in Zanesville, Loring 2, Loring 1, and Dundee soils. Plants on all unlimed soils showed characteristic manganese toxicity symptoms; however, these were much more severe on Zanesville than on other soils. Yields on the unlimed soils varied widely, with Zanesville producing only about one-fourth as much as Loring 2, Loring 1, and Dundee. Such yield differences cannot be explained by differences in exchangeable calcium or extractable aluminum. The most obvious difference between Zanesville and the other three soils was that Zanesville contained a higher level of exchangeable manganese and produced alfalfa plants having higher concentrations of manganese in their tops.

Yield response to lime was accompanied by large reductions in exchangeable manganese in soils, complete correction of toxic plant symptoms, and marked decreases in manganese contents of plants. Yield increases obtained with the peat treatment were also associated with correction of toxic symptoms and large decreases in manganese uptake by plants; however, this treatment did not reduce levels of exchangeable manganese except on Dundee soil. Apparently, the peat treatment reduced the availability of exchangeable manganese to plants.

The high phosphate treatment increased yields and percentages of phosphorus in plants and decreased manganese uptake but did not completely correct the toxic leaf symp-

toms. Plants on this treatment were slender and pale in color when compared with those grown on limed soils. The yield increases obtained with this treatment, especially on Zanesville soil, appeared large in proportion to the decreases in manganese contents of plants. This suggests that high phosphorus levels in soils and plants provide some protection against manganese injury and is in accordance with the work of Bortner (*7*), who reported that phosphate treatments greatly reduced manganese toxicity in tobacco. Phosphate fertilization would also be expected to reduce aluminum toxicity, if present (*10*), but the evidence indicates that excess aluminum is not the primary problem in these acid soils.

The yield increase obtained with sand on Zanesville soil is attributed to dilution of manganese in the soil and in plants.

Severe yield decreases obtained with the $CaCl_2$ treatment were associated with increased toxicity symptoms and manganese uptake by plants and with great increases in exchangeable manganese in soils.

Yield increases obtained with lime, phosphate, peat, and sand were generally associated with decreases in extractable aluminum in soils, but such decreases do not adequately explain observed differences in yields between unlimed soils or differences in lime response. For example, Dundee soil contained a higher level of KCl extractable aluminum than Zanesville, but yielded three times as much alfalfa when both were unlimed. Yields on the four soils were not closely related to concentrations of Ca, P, Fe, or Al in plants. When all soils and all treatments are considered, the factors most closely related to alfalfa yield were exchangeable manganese in soils and manganese contents of plants.

Two samples of Zanesville soil, taken from points that were only 10 feet apart in the field, differed markedly in toxicity to alfalfa and response to lime when studied in separate experiments (table 4). Differences in exchangeable calcium and aluminum do not explain the results. Table 4 shows that the soil in experiment 1b, which showed the greatest toxicity and lime response, contained 50 percent more exchangeable manganese, and that it was adjusted to a lower phosphate level. Although plants from experiment 1a were not analyzed, those from experiment 1b (appendix table 6) contained a very high concentration of manganese (1,835 p.p.m). The higher phosphate level in the soil of experiment 1a

TABLE 4.—*Characteristics of two samples of Zanesville soil from the same site that gave widely different lime responses in experiments 1a and 1b, Fayetteville, Ark.*

Experiment	Alfalfa yield	pH value	Soil characteristics				
			Cation-exchange-capacity	Exchange-able Ca	Extract-able Al[1]	Exchange-able Mn	Available phos-phorus
	G./pot		*Meq./100 g.*	*Meq./100 g.*	*Meq./100 g.*	*P.p.m.*	*Lb. P/acre*
Experiment 1a:							
No lime	8. 04	4. 6	5. 5	2. 40	1. 29	48	175
Lime	10. 70	7. 6	-------	-------	. 63	8	-------
Experiment 1b:							
No lime	1. 19	4. 5	6. 9	2. 56	1. 36	72	86
Lime	6. 80	7. 5	-------	-------	. 59	11	-------

[1] Extracted with NH_4OAc at pH 4.8.

may have masked the normal lime response by reducing the level of exchangeable manganese in the soil or by reducing the toxicity of the manganese that was actually absorbed by plants. Results listed in appendix table 6 show that for the Zanesville soil yield increases obtained by phosphate fertilization are large in comparison with the decreases in manganese contents of plants. This suggests that phosphorus may detoxify manganese within the plant.

Manganese toxicity is believed to be the primary growth-limiting factor on acid Waynesboro, Cecil, Johnsburg, Loring 1, Zanesville, Dundee, Taloka complex, Loring 2, and Calloway soils. Two other soils, Vaiden (pH 5.7) and Decatur (pH 5.5), contained extremely high levels of exchangeable manganese (128 to 136 p.p.m.) (appendix tables 9 and 11), but alfalfa showed essentially no reponse to lime on Vaiden and very little on Decatur. Plants on these soils did not accumulate high concentrations of manganese nor show any of the characteristic symptoms of manganense toxicity (appendix tables 10 and 12). Results of plant and soil analysis indicate that higher levels of calcium in these soils may have prevented excessive uptake of manganese by plants.

Aluminum Toxicity

In experiment 3, unlimed Bladen soil was extremely toxic to alfalfa. Plants died before reaching a height of 1 inch. Plant symptoms preceding death were identical to those of extreme phosphorus deficiency and to those produced by excess aluminum in sand culture studies by the author. Leaves were small and abnormally dark green with a purple tinge. These symptoms are entirely different from those of manganese toxicity described in the preceding section. Leaves died and dropped off one at a time, starting at the bottom. Top leaves stayed purplish green almost until death. Exchangeable manganese was so low (2 p.p.m.) as to rule out the possibility of manganese toxicity in this soil.

Figure 6 shows that yield increases obtained with lime on the Bladen soil are associated with decreases in KCl (pH 7.0)-extractable aluminum below 0.5 meq./100 g. of soil. A similar relationship was found between lime response and decrease in NH_4OAc (pH 4.8)-extractable aluminum below 3 meq./100 g. Over the same range of aluminum concentration, yields on the Bayboro soil were essentially unaffected by liming.

Alfalfa yields on unlimed Bayboro were much greater than those on unlimed Bladen at comparable pH and extractable aluminum levels. The reasons for this are not known at present, but the following explanations seem reasonable. First, when extractable aluminum is expressed as a percentage of the soil exchange capacity, the value for Bladen is more than double that for Bayboro (appendix table 9). Thus, in the Bladen soil a higher proportion of the aluminum may have been available to plant roots. Second, since Bayboro is higher in organic matter, the toxicity of aluminum may have been reduced through chelation in the soil. Although the exact mechanism of aluminum toxicity is not known, the injury has been associated with reduced uptake of phosphorus (*32*) and calcium (*27*) by plants. Bayboro soil may be less toxic than Bladen, because it contains higher concentrations of effective aluminum-chelating materials such as organic acids (*16*), which would be expected to reduce the precipitation of phosphorus by aluminum outside and inside the plant and to reduce the competition between calcium and aluminum for absorption by plant roots.

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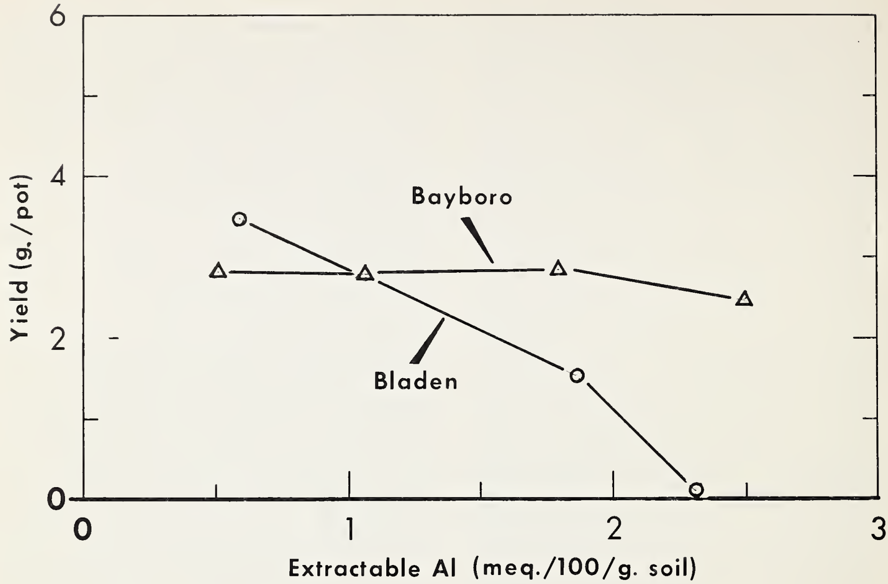

FIGURE 6.—Relationship between alfalfa yield and level of KCl (pH 7.0)-extractable aluminum on Bladen and Bayboro soils: Experiment 3.

Bayboro soil contained twice as much calcium as Bladen on an absolute basis, but the two soils were about equal in percentage of calcium saturation. At the one-ton lime rate plants on Bayboro contained higher concentration of calcium, magnesium, manganese, aluminum, sodium, and copper, but less phosphorus than those on Bladen (appendix table 10).

Lime response on Bladen soil was associated with increased calcium uptake, but it is doubtful that calcium deficiency, as such, limited yields on this acid soil. When yields were increased with lime, the phosphorus and aluminum contents of plants were increased slightly, whereas magnesium contents were decreased.

The evidence indicates that aluminum toxicity is the primary growth-limiting factor in acid Bladen soil; however, gross plant analysis did not permit clarification of the nature of aluminum injury in plants.

Calcium Deficiency

Absolute calcium deficiency appears to be the first growth-limiting factor in acid Leon soil. Plants on the unlimed soil showed general chlorosis and stunting and died before the first harvest. Yield increases obtained by liming were closely correlated with increases in the percentage of calcium in plant tops (fig. 7). This relationship apparently does not hold for the Bladen soil, although the calcium percentage in plants was increased by the first increment of lime. Lime response on Leon soil was accompanied by decreases in KCl-extractable aluminum in the soil and in aluminum contents of plants, but it appears doubtful that aluminum is high enough to be toxic in this soil (appendix tables 9 and 10). Yield increases obtained with lime were also associated with decreases in the phosphorus, magnesium, boron, manganese, and iron concentrations of plants. Manganese concentrations of plants were certainly

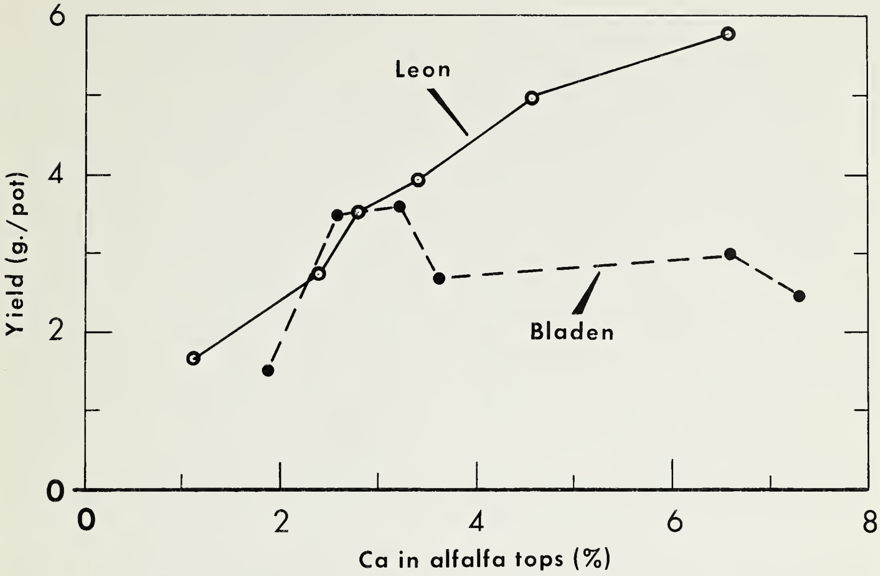

FIGURE 7.—Relationship between alfalfa yield and percentage calcium in plant tops on Bladen and Leon soils: Experiment 3.

too low to be toxic, but boron concentrations were quite high and may be approaching the toxic level.

Combinations of Growth-Limiting Factors

The evidence obtained does not permit positive identification of the toxic factors on acid Lakeland, Tifton, and Rains soils. Combinations of various factors appear to be involved. Alfalfa plants on unlimed Lakeland soil appeared to be calcium deficient. Chlorosis was generally distributed over the leaves, instead of being confined largely to leaf margins, as in manganese toxicity. Soil and plant analyses also suggested that calcium deficiency was at least partially limiting growth (appendix tables 7 and 8); however, there is the possibility that the aluminum level in this sandy soil was high enough to produce toxicity of its own or to intensify the calcium deficiency already present. Excess aluminum has been shown to reduce the uptake of calcium by alfalfa plants (*27*). Lakeland soil was very low in exchangeable manganese, but plants on the unlimed soil accumulated 540 p.p.m., which is near the level expected for toxicity to start. However, the characteristic symptoms of manganese injury were not present. As on Leon soil, alfalfa plants on unlimed Lakeland soil accumulated high concentrations of boron (appendix table 8), but the significance of this was not determined. Lime response of alfalfa on Lakeland soil was accompanied by increased concentrations of calcium and decreased concentrations of boron and manganese in plants. The concentrations of phosphorus and aluminum in plants were not appreciably affected by liming.

Plants on unlimed Tifton soil were stunted and showed an overall yellowing, which suggests calcium deficiency or aluminum toxicity, or both; however, the level of exchangeable alumnium in the soil appeared too low to cause toxicity (appendix table 11). These plants contained 420 p.p.m. manganese,

but the symptoms of manganese toxicity (marginal leaf chlorosis) were absent. Alfalfa yield increases obtained with lime on this soil were associated with decreases in extractable aluminum and exchangeable manganese in the soil and with increases in the calcium and decreases in the manganese concentrations of plants. Lime response was accompanied by slight increases in the phosphorus and iron and decreases in the boron and magnesium concentrations of plants. Alumnium concentrations of alfalfa plants on Tifton soil were slightly increased by liming (appendix tables 11 and 12).

Alfalfa plants on unlimed Rains soil showed some leaf marginal chlorosis that resembles manganese toxicity and also a stunting of growth, which is characteristic of aluminum injury. Although the manganese contents of plants were decreased with increased lime rates, the highest manganese content was probably too low to cause toxicity (appendix table 12). Results of plant analyses suggest that calcium deficiency limited growth on the unlimed soil. Lime response was associated with a doubling of the calcium concentrations of plants. Yield increases obtained with lime were also related in a general way to decreases in extractable aluminum in soils. Mathers and Coleman (*18*) have concluded that low calcium and aluminum toxicity limit plant growth on this soil.

Growth-Limiting Factors in Limed Soils

Alfalfa yields were decreased by liming above pH 5.0 on Johnsburg and Bayboro, pH 5.5 on Waynesboro, Bladen, and Rains, pH 6.0 on Taloka complex, pH 6.3 on Lakeland, pH 7.0 on Vaiden, and pH 7.3 on Tifton. Yield decreases associated with liming were more severe on Rains and Bladen than on the other soils of this group (figs. 1 through 4). The sharp yield depression in Rains soil does not appear to be related to any marked changes in plant composition. In general, yield reductions on these soils were accompanied by chlorosis of older leaves of plants; however, on the Vaiden soil both old and young leaves were affected. Yield decreases on the Waynesboro, Lakeland, Johnsburg, and Taloka complex soils were associated with decreases in the manganese contents of plants (appendix tables 7 and 8); however, it is not known whether or not manganese deficiency actually limited yields. The manganese content of plants on Lakeland soil was very low. On Bladen soil, yield increases obtained by liming above pH 5.5 were associated with decreases in the boron and iron concentrations in plants (appendix tables 9 and 10).

Further study will be required to identify the yield-limiting factors on these limed soils.

SUMMARY AND CONCLUSIONS

Greenhouse experiments were conducted to identify toxic factors in 17 acid soils of the Southeastern United States, and to relate levels of such factors to lime response of alfalfa.

Results indicate that manganese toxicity is the primary limiting factor in the growth of alfalfa on acid Johnsburg (pH 5.1), Taloka complex (pH 5.2), Zanesville (pH 4.9), Loring 2 (pH 5.1), Loring 1 (pH 5.3), Dundee (pH 4.8), Calloway (pH 5.4), Cecil (pH 5.2), and Waynesboro (pH 5.2) soils. Significant yield responses to applications of lime on these nine soils were closely associated with decreases in exchangeable manganese in the soils and with decreases in toxic symp-

toms and manganese contents of plants. Liming these soils reduced levels of extractable aluminum, but the evidence for aluminum toxicity is weak in comparison with that for manganese toxicity.

Two other high-manganese soils, Decatur (pH 5.5) and Vaiden (pH 5.8), did not give significant yield responses with lime, and plants did not accumulate high concentrations of manganese or show symptoms of manganese toxicity. The reason for this was not determined, but it may be due to higher levels of exchangeable calcium in these soils which could prevent excessive uptake of manganese by plants through ion competition.

Aluminum toxicity appears to be the primary growth-limiting factor in acid Bladen soil (pH 4.8). Alfalfa yield responses to applications of lime on this soil were closely related to decreases in extractable aluminum in the soil. Plant symptoms on the acid soil resembled those of extreme phosphorus deficiency and were identical to those produced by excess aluminum in sand culture.

Bayboro soil (pH 4.3) contained as much extractable aluminum as Bladen, but the Bayboro soil was much less toxic to alfalfa and did not give a significant response to lime. The reason for this was not determined; however, it may be due to the fact that Bayboro had a higher organic matter content and, as a result, a lower percentage of aluminum saturation. The toxicity of aluminum may also have been reduced through chelation in the Bayboro soil.

Calcium deficiency appears to be the first limiting factor in acid Leon soil (pH 4.2). Linear alfalfa yield increases obtained by liming Leon soil to pH 7.0 were accompanied by linear increases in the percentage of calcium in plants.

Yield-limiting factors in acid Lakeland, Tifton, and Rains soils were not conclusively identified. Results of soil and plant analyses and observations of plant symptoms suggest that calcium deficiency limited alfalfa yields to some extent on all three unlimed soils. On Lakeland and Rains soils aluminum toxicity also apears to be involved. There was weak evidence for manganese toxicity on Lakeland and Tifton soils.

Results of these studies have emphasized that acid Southeastern soils having equal pH values vary widely in their toxicities to alfalfa. In some soils, poor growth can be closely related to one factor, such as calcium deficiency in Leon and aluminum toxicity in Bladen. In other soils, more than one factor is involved but one factor appears to be dominant. In still others, toxicity may be associated with a complex of interacting factors that is difficult to define.

It should be emphasized that these studies were conducted with surface soils under greenhouse conditions. The results obtained are, therefore, more nearly representative of the seedling establishment stage than of subsequent periods of alfalfa growth. Under field conditions subsoil characteristics would also be important in determining the long-term growth of plants, and lime response might become considerably more complicated. For example, liming an acid surface soil that is high in aluminum would reduce the solubility of aluminum sufficiently to permit alfalfa seedling establishment, but a high aluminum subsoil could prevent root penetration below the limed layer and thus cause plants to suffer from drought. Development of the most effective liming practices will, therefore, also require studies on the growth-limiting factors in acid subsoils.

Alfalfa yields tended to decrease with liming above pH 5.0 on Johnsburg and Bayboro, pH 5.5 on

Waynesboro, Bladen, and Rains, pH 6.0 on Taloka complex, pH 6.3 on Lakeland, pH 7.0 on Vaiden, and pH 7.6 on Tifton. Yield decreases associated with liming were more severe on Rains and Bladen than on the other soils of this group. Chlorotic symptoms were observed, but the causes of yield depression were not determined. Overliming effects on these soils should receive further study.

LITERATURE CITED

(1) Adams, F., and Wear, J. I.
1957. MANGANESE TOXICITY AND SOIL ACIDITY IN RELATION TO CRINKLE LEAF OF COTTON. Soil Sci. Soc. Amer. Proc. 21: 305–308.

(2) Albrecht, W. A.
1932. CALCIUM AND HYDROGEN ION CONCENTRATION IN THE GROWTH AND INOCULATION OF SOYBEANS. Amer. Soc. Agron. Jour. 24: 793–806.

(3) ———
1941. CALCIUM BEARING VERSUS NEUTRAL FERTILIZERS. Com. Fert. Yearbook 1941, pp. 23–40.

(4) ——— and Davis, F. L.
1929. PHYSIOLOGICAL IMPORTANCE OF CALCIUM IN LEGUME INOCULATION. Bot. Gaz. 88: 310–332.

(5) ——— and Smith, G. E.
1952. SOIL ACIDITY AS CALCIUM (FERTILITY) DEFICIENCY. Internatl. Soc. Soil. Sci. Trans. (5th Cong.) 1: 119–135.

(6) Aslander, A.
1929. [CONCENTRATION OF THE NUTRIENT MEDIUM VERSUS ITS HYDROGEN ION CONCENTRATION AS MANIFESTED BY PLANT GROWTH.] Svensk. Bot. Tidskr. 23: 96–140. (Chem. Abs. 27: 2710. 1933.)

(7) Bortner, C.
1935. MANGANESE TOXICITY ON TOBACCO. Soil Sci. 39: 15–34.

(8) Bray, R. H., and Kurtz, L. T.
1945. DETERMINATION OF TOTAL ORGANIC AND AVAILABLE FORMS OF PHOSPHORUS IN SOILS. Soil Sci. 59: 39–45.

(9) Breazeale, J. F., and Le Clerc, J. A.
1912. GROWTH OF WHEAT SEEDLINGS AS AFFECTED BY ACID OR ALKALINE CONDITIONS. U.S. Dept. Agr. Bur. Chem. Bul. 149, 18 pp.

(10) Burgess, P. S., and Pember, F. R.
1923. ACTIVE ALUMINUM AS A FACTOR DETRIMENTAL TO CROP PRODUCTION IN MANY ACID SOILS. R. I. Agr. Expt. Sta. Bul. 194, 40 pp.

(11) Chenery, E. M.
1948. THIOGLYCOLLIC ACID AS AN INHIBITOR FOR IRON IN THE COLORIMETRIC DETERMINATION OF ALUMINUM BY MEANS OF "ALUMINON." Analyst 73: 501–502.

(12) Foy, C. D., and Barber, S. A.
1959. MOLYBDENUM RESPONSE OF ALFALFA OF INDIANA SOILS IN THE GREENHOUSE. Soil Sci. Soc. Amer. Proc. 23: 36–39.

(13) Giddens, J., and Perkins, H. F.
1960. INFLUENCE OF MOLYBDENUM ON GROWTH AND COMPOSITION OF ALFALFA AND DISTRIBUTION OF MOLYBDENUM IN A CECIL-LLOYD SOIL. Soil Sci. Soc. Amer. Proc. 24: 496–497.

(14) Heslep, J. M.
1951. A STUDY OF THE INFERTILITY OF TWO ACID SOILS. Soil Sci. 72: 67–80.

(15) Jackson, M. L.
1958. SOIL CHEMICAL ANALYSIS. 498 pp. Prentice-Hall, Inc., Englewood Cliffs, N.J.

(16) Jones, L. H.
1961. ALUMINUM UPTAKE AND TOXICITY IN PLANTS. Plant and Soil 13 (4): 297–310.

(17) Kliewer, W. M., and Kennedy, W. K.
1960. STUDIES ON RESPONSE OF LEGUMES TO MOLYBDENUM AND LIME FERTILIZATION ON MARDIN SILT LOAM SOIL. Soil Sci. Soc. Amer. Proc. 24: 377–380.

(18) Mathers, A. C., and Coleman, N. T.
1925. ALUMINUM POISONS PLANTS IN ACID SOILS. N.C. Agr. Expt. Sta., Res. and Farm. 16 (4): 13.

(19) MAGISTAD, O. C.
1925. THE ALUMINUM CONTENT OF THE SOIL SOLUTION AND ITS RELATION TO SOIL REACTION AND PLANT GROWTH. Soil Sci. 20: 181–225.

(20) McLEAN, E. O., HEDDLESON, M. R., BARTLETT, R. J., and HOLOWAYCHUK, N.
1958. ALUMINUM IN SOILS. I. EXTRACTION METHODS AND MAGNITUDES IN CLAYS AND OHIO SOILS. Soil Sci. Soc. Amer. Proc. 22: 382–387.

(21) McLEAN, F. T., and GILBERT, B. E.
1928. ALUMINUM TOXICITY. Plant Physiol. 3: 293–302.

(22) MORRIS, H. D.
1948. THE SOLUBLE MANGANESE CONTENT OF ACID SOILS AND ITS RELATION TO THE GROWTH AND MANGANESE CONTENT OF SWEET CLOVER AND LESPEDEZA. Soil Sci. Soc. Amer. Proc. 13: 362–371.

(23) MOSCHLER, W. W., JONES, G. D., and THOMAS, G. W.
1960. LIME AND SOIL ACIDITY EFFECTS ON ALFALFA GROWTH IN A RED-YELLOW PODZOLIC SOIL. Soil Sci. Soc. Amer. Proc. 24: 507–509.

(24) OLSEN, C.
1958. IRON ABSORPTION IN DIFFERENT PLANT SPECIES AS A FUNCTION OF THE pH VALUE OF THE SOLUTION. Carlsberg Lab. Compt. Rend. des. Trav. Sér. Chim. 31: 41–59.

(25) RAGLAND, J. L., and COLEMAN, N. T.
1959. THE EFFECT OF SOIL SOLUTION ALUMINUM AND CALCIUM ON ROOT GROWTH. Soil Sci. Soc. Amer. Proc. 23: 355–357.

(26) SCHMEHL, W. R., PEECH, M., and BRADFIELD, R.
1950. CAUSES OF POOR GROWTH OF PLANTS ON ACID SOILS AND BENEFICIAL EFFECTS OF LIMING. I. EVALUATION OF FACTORS RESPONSIBLE FOR ACID SOIL INJURY. Soil Sci. 70: 393–410.

(27) ——— PEECH, M., and BRADFIELD, R.
1952. INFLUENCE OF SOIL ACIDITY ON ABSORPTION OF CALCIUM BY ALFALFA AS REVEALED BY RADIOCALCIUM. Soil Sci. 73: 11–21.

(28) SPURWAY, C. H.
1933. SOIL TESTING—A PRACTICAL SYSTEM OF SOIL DIAGNOSIS. Mich. Agr. Expt. Sta. Tech. Bul. 132, 16 pp.

(29) VLAMIS, J.
1953. ACID SOIL INFERTILITY AS RELATED TO SOIL SOLUTION AND SOLID PHASE EFFECTS. Soil Sci. 75: 383–394.

(30) WOODRUFF, C. M.
1947. DETERMINATION OF EXCHANGEABLE HYDROGEN AND LIME REQUIREMENT BY MEANS OF A GLASS ELECTRODE AND BUFFERED SOLUTION. Soil Sci. Soc. Amer. Proc. 12: 141–142.

(31) WRIGHT, K. E.
1937. EFFECTS OF LIME AND PHOSPHORUS IN REDUCING ALUMINUM TOXICITY OF ACID SOILS. Plant Physiol. 12: 173–181.

(32) ——— and DONAHUE, B. A.
1952. ALUMINUM TOXICITY STUDIES WITH RADIOACTIVE PHOSPHORUS. Plant Physiol. 28: 674–680.

APPENDIX

Table 5.—*Effects of lime application rate on alfalfa yield and soil characteristics 5 months after liming, experiment 1a, Fayetteville, Ark.*

Soil	$CaCO_3$	pH value	Alfalfa yield [1]	Extractable aluminum by NH_4OAc method [2]		Exchange-able Mn [3]
	Tons/acre		*G./pot*	*Meq./100 g.*	*Pct. of CEC*[4]	*P.p.m.*
Calloway	0	5.3	7.61	0.93	12.3	39
	0.5	5.8	7.68	.73	9.6	21
	1.0	6.3	9.54	.62	8.2	21
	1.5	6.8	9.28	.51	6.7	--------
	2.0	7.1	10.30	.51	6.7	--------
	2.5	7.4	10.23	.47	6.2	--------
	3.0	7.6	9.93	.47	6.2	8
	4.0	7.8	9.57	.49	6.5	--------
	6.0	7.8	9.51	.54	7.1	--------
Dundee	0	4.7	5.91	2.02	10.3	49
	.5	4.8	7.17	1.60	8.1	37
	1.0	5.1	7.26	1.57	8.0	18
	1.5	5.4	10.31	1.64	8.4	--------
	2.0	5.8	9.91	1.37	7.0	--------
	2.5	6.1	10.70	1.16	6.0	--------
	3.0	6.6	13.08	1.11	5.7	13
	4.0	7.0	12.94	1.04	5.3	--------
	6.0	7.5	13.91	.96	4.9	--------
Loring 1	0	4.9	3.38	1.74	13.5	59
	.5	5.3	5.26	1.53	11.9	18
	1.0	5.8	8.41	1.44	11.2	15
	1.5	6.5	9.88	1.57	12.2	--------
	2.0	7.0	9.34	1.42	11.0	--------
	2.5	7.4	9.96	1.43	11.1	--------
	3.0	7.5	10.45	1.26	9.8	5
	4.0	7.9	9.99	1.30	10.1	--------
	6.0	7.9	10.56	1.42	11.0	--------
Loring 2	0	4.5	2.88	1.09	21.9	67
	.5	5.8	7.81	.79	15.9	20
	1.0	5.9	8.86	.70	14.1	14
	1.5	6.3	9.51	.65	13.1	--------
	2.0	6.8	8.01	.53	10.6	--------
	2.5	7.2	9.76	.59	11.9	--------
	3.0	7.3	9.35	.65	13.1	8
	4.0	7.6	9.71	.60	12.1	--------
	6.0	7.7	10.55	.68	13.7	--------
Zanesville	0	4.6	8.04	1.29	23.4	48
	.5	5.2	9.73	.87	15.8	26
	1.0	5.7	9.36	.76	13.8	12
	1.5	6.3	10.21	.72	13.0	--------
	2.0	6.7	9.93	.69	12.5	--------
	2.5	7.1	9.30	.65	11.8	--------
	3.0	7.3	9.91	.61	11.1	--------
	4.0	7.6	10.70	.63	11.4	8
	6.0	7.7	9.97	.57	10.3	--------

[1] Total of three cuttings—average of three replications. For comparing yields at any lime level with those of the check within a soil, the difference required for significance at the 5-percent level by *t*-test (L.s.d.) is 1.45 g./pot.
[2] NH_4OAc at pH 4.8.
[3] Extracted with $1N$ NH_4OAc at pH 7.0. Values are averages of duplicate determinations on composite samples from three pots.
[4] Cation-exchange-capacity by NH_4OAc method.

TABLE 6.—*Effects of lime, phosphorus, peat, sand, and calcium chloride additions on soil properties and on alfalfa yield and composition, experiment 1b, Fayetteville, Ark.*

Soil and treatment [1]	Alfalfa yield [2]	Soil properties						Plant composition					
		pH value	Extractable aluminum [3] by—				Exchangeable Mn [4]	Ca	Mn	Al	Fe	Ca	P
			NH₄OAc method		KCl method								
	G./pot		*Meq./100 g.*	*Pct. of CEC* [5]	*Meq./100 g.*	*Pct. of CEC* [5]	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*Pct.*	*Pct.*
Dundee:													
Check	4.17	4.7	1.51	7.5	0.44	2.18	55	1,150	651	93	106	1.10	0.44
Lime	7.19	7.3	.77	3.8	.00	.00	7	2,833	125	102	117	1.48	.30
High P	5.81	4.8	.94	4.7	.12	.57	54	1,433	453	53	129	.93	.62
Peat	7.29	5.2	.93	3.6	.02	.11	32	1,766	166	135	89	.95	.24
Sand	4.44	4.8	.67	7.1	.07	.35	24	783	506	73	100	.91	.32
$CaCl_2$	2.60	4.4	1.55	7.7	.16	.79	101	1,550	1,055	33	122	1.75	.20
Loring 1:													
Check	3.57	5.0	1.18	12.2	.03	.40	34	616	756	118	162	1.44	.32
Lime	6.25	7.4	1.05	10.9	.00	.00	6	1,916	141	103	116	1.97	.29
High P	5.31	5.2	.86	8.9	.00	.00	38	783	453	128	123	1.34	.48
Peat	6.39	5.6	.54	3.0	.02	.32	37	1,250	216	115	118	1.39	.27
Sand	4.14	5.1	.73	16.9	.00	.00	17	433	431	130	172	.82	.30
$CaCl_2$	1.85	4.8	.98	10.2	.02	.32	71	883	1,253	100	105	1.65	.22

Loring 2:													
Check	4. 42	5. 0	. 74	15. 0	. 03	. 57	39	383	797	113	83	1. 09	. 23
Lime	6. 60	7. 7	. 34	6. 9	. 00	. 00	11	1, 416	125	175	100	1. 39	. 26
High P	5. 50	5. 2	. 58	11. 8	. 00	. 00	46	516	667	149	119	1. 57	. 61
Peat	4. 57	5. 4	. 43	3. 7	. 02	. 41	44	1, 000	265	150	130	1. 47	. 22
Sand	3. 99	5. 2	. 53	27. 7	. 03	. 69	31	283	957	123	137	. 93	. 33
$CaCl_2$	. 70	4. 7	. 71	14. 4	. 01	. 22	96	683	1, 908	30	277	1. 85	. 30
Zanesville:													
Check	1. 19	4. 5	1. 36	19. 8	. 18	2. 66	72	500	1, 835	125	123	1. 63	. 23
Lime	6. 80	7. 5	. 59	8. 6	. 00	. 00	11	1, 600	65	88	92	1. 66	. 26
High P	4. 58	4. 8	. 85	12. 4	. 00	. 00	63	716	1, 390	75	133	1. 44	. 50
Peat	2. 38	5. 0	. 58	4. 1	. 01	. 16	64	1, 167	571	118	105	1. 72	. 23
Sand	3. 61	4. 9	. 85	26. 4	. 03	. 36	37	400	1, 126	75	133	. 97	. 26
$CaCl_2$	. 48	4. 5	1. 01	14. 7	. 07	. 98	116	833	3, 880	34	51	2. 27	. 21

[1] Key to treatments:
Check—*Basal treatment:* 25 lb. N, 87 lb. P, 249 lb. K, 30 lb. Mg, and 4.54 lb. B per acre.
Lime—Basal plus 4 tons reagent grade $CaCO_3$ per acre.
High P—Basal plus 873 lb. P (as monocalcium phosphate) per acre.
Peat—Basal plus 5 percent by weight; pH of peat was 5.5.
Sand—Basal plus 50 percent sand by weight.
$CaCl_2$—Basal plus 800 lb. Ca/acre, which is one-fourth the calcium equivalent of the lime treatment.

[2] Total of three cuttings—average of three replications. For comparing yields of any treatment with those of the check within a soil, the difference required for significance at the 5-percent level by *t*-test (L.s.d.) is 1.22 g./pot.

[3] NH_4OAc at pH 4.8 and 1 *N* KCl at pH 7.0.

[4] Extracted with 1 *N* NH_4OAc at pH 7.0.

[5] Cation-exchange-capacity of soil or soil-peat, or soil-sand mixtures by NH_4OAc method.

TABLE 7.—*Effects of lime application rate on alfalfa yields and soil properties, experiment 2, Fayetteville, Ark.*

Soil	$CaCO_3$	pH value	Alfalfa yield [1]	Extractable aluminum [2] by—				Exchangeable Mn [3]
				NH_4OAc method		KCl method		
	Tons/acre		*G./pot*	*Meq./100 g.*	*Pct. of CEC* [4]	*Meq./100 g.*	*Pct. of CEC* [4]	*P.p.m.*
Cecil	0	4.6	0.74	1.37	25.8	0.13	2.49	99
	1	6.0	8.04	.89	16.8	.01	.21	50
	2	6.7	7.96	.90	17.0	.02	.36	32
	3	7.0	9.58	1.03	19.4	.00	.00	28
Johnsburg	0	4.4	5.28	1.75	23.0	.55	7.20	80
	1	5.0	8.56	1.11	14.6	.05	.64	38
	2	5.8	7.59	.90	11.8	.01	.16	31
	3	6.6	7.44	.73	9.6	.01	.12	24
Lakeland	0	4.5	3.14	1.86	48.9	.56	14.84	5
	1	5.5	6.08	1.72	45.3	.05	1.29	2
	2	6.3	8.15	2.03	53.4	.03	.79	2
	3	6.7	6.95	1.97	51.8	.02	.47	2
Taloka-Parsons-Johnsburg	0	4.5	6.72	1.46	20.0	.35	4.79	66
	1	5.2	8.46	1.09	14.9	.02	.32	30
	2	6.0	8.37	.75	10.3	.02	.23	23
	3	6.5	7.74	.68	9.3	.02	.29	17
Waynesboro	0	4.5	1.40	2.11	33.5	.40	6.41	138
	1	5.4	9.23	.97	15.4	.01	.13	49
	2	6.3	8.62	.85	13.5	.01	.17	37
	3	7.1	7.80	.74	11.7	.02	.32	24

[1] Total of two cuttings:—Average of two replications. For comparing yield at any lime level with that of the check within a soil, the difference required for significance at the 5-percent level by *t*-test (L.s.d.) is 0.73 g./pot.
[2] NH_4OAc at pH 4.8 and 1 *N* KCl at pH 7.0.
[3] Extracted with 1 *N* NH_4OAc at pH 7.0.
[4] Cation-exchange-capacity by NH_4OAc method.

TABLE 8.—*Effects of different lime levels on the composition of alfalfa tops, experiment 2, Fayetteville, Ark.*

Soil	$CaCO_3$	Plant composition [1]									
		K	Ca	P	Mg	B	Mn	Al	Na	Fe	Cu
	T./acre	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*
Cecil	0	4. 6	2. 6	0. 30	0. 74	65	1, 430	240	300	170	4. 6
	1	4. 0	1. 8	. 26	. 19	89	320	190	66	250	8. 0
	2	3. 6	1. 8	. 24	. 16	76	190	160	58	200	9. 2
	3	3. 2	1. 9	. 24	. 18	72	220	240	72	300	7. 2
Johnsburg	0	4. 2	1. 30	. 22	. 30	100	1, 660	230	190	320	15. 0
	1	3. 3	1. 60	. 22	. 18	89	460	180	98	260	12. 0
	2	3. 3	1. 90	. 22	. 16	80	240	190	90	250	10. 0
	3	3. 5	2. 30	. 28	. 16	110	160	200	110	250	8. 6
Lakeland	0	4. 3	. 61	. 20	. 37	340	540	170	200	290	9. 2
	1	3. 5	1. 50	. 22	. 20	160	110	180	80	280	7. 2
	2	3. 1	1. 60	. 18	. 16	110	86	200	80	290	6. 8
	3	3. 2	1. 60	. 18	. 13	100	54	150	72	200	9. 8
Taloka-Parsons-Johnsburg	0	3. 0	1. 90	. 24	. 24	94	1, 100	200	560	240	9. 2
	1	2. 9	2. 00	. 22	. 17	94	250	230	120	250	6. 4
	2	3. 1	2. 40	. 22	. 17	86	190	200	130	250	7. 6
	3	3. 3	2. 50	. 20	. 14	69	120	180	110	230	5. 6
Waynesboro	0	4. 6	1. 2	. 20	. 35	89	1, 970	150	160	230	5. 3
	1	3. 5	1. 7	. 24	. 19	94	240	190	98	260	8. 0
	2	3. 6	2. 0	. 24	. 17	86	170	200	72	240	5. 9
	3	3. 4	2. 0	. 22	. 14	65	150	190	37	220	6. 8

[1] Values are averages of two replications.

TABLE 9.—*Effects of lime rate on alfalfa yields and soil properties, experiment 3, Fayetteville, Ark.*

Soil	$CaCO_3$	pH value	Alfalfa yield [1]	Extractable aluminum [2] by				Exchange-able Mn [3]
				NH₄OAc method		KCl method		
	T./acre		*G./pot*	*Meq./100 g.*	*Pct. of CEC* [4]	*Meq./100 g.*	*Pct. of CEC* [4]	*P.p.m.*
Bayboro	0	4.3	2.45	5.29	17.6	2.51	8.33	3.70
	1	4.6	2.81	4.93	16.4	1.80	6.00	2.27
	2	4.7	2.79	5.05	16.8	1.07	3.55	2.02
	3	4.9	2.80	3.95	13.1	.51	1.69	1.96
	4	5.2	1.98	4.47	14.9	.05	.16	1.44
	6	5.5	1.98	3.46	11.5	.04	.13	1.25
	8	5.9	2.52	3.09	10.3	.02	.06	.46
Bladen	0	4.2	.01	4.22	36.4	2.32	20.00	1.81
	1	4.4	1.50	4.00	34.5	1.87	16.10	1.30
	2	4.9	3.44	2.79	24.1	.58	5.00	1.17
	3	5.4	3.59	2.01	22.5	.04	.30	.58
	4	5.8	2.66	2.26	19.5	.03	.26	.46
	6	6.9	2.94	1.79	15.4	.04	.30	.19
	8	7.1	2.44	1.55	13.4	.05	.43	.23
Leon	0	4.0	.62	.20	4.1	.27	5.51	.40
	1	4.6	1.65	.29	5.9	.05	1.02	.31
	2	5.1	2.69	.09	1.8	.02	.41	.23
	3	5.9	3.51	.13	2.7	.01	.20	.29
	4	6.6	3.93	.11	2.2	.03	.50	.25
	6	7.2	5.78	.09	1.8	.03	.50	.02
	8	7.4	4.96	.05	1.0	.02	.45	.29
Vaiden	0	5.7	6.55	.62	1.9	.03	.80	128.80
	1	6.1	6.23	.48	1.5	.01	.40	101.70
	2	6.6	7.11	.44	1.3	.04	1.07	66.00
	3	6.9	6.95	.56	1.7	.04	1.23	49.20
	4	7.0	6.64	.37	1.1	.03	.98	39.90
	6	7.2	5.42	.43	1.3	.04	1.26	32.40
	8	7.2	5.81	.47	1.4	.03	.86	37.80

[1] Total of three cuttings—average of three replications. For comparing yield at any lime level with that of the check within a soil, the difference required for significance at the 5 percent level by *t*-test (L.S.D.) is 0.83 g./pot.

[2] NH_4OAc at pH 4.8 and 1 *N* KCl at pH 7.0.

[3] Extracted with 1 *N* NH_4OAc at pH 7.0.

[4] Cation-exchange-capacity by NH_4OAc method.

TABLE 10.—*Effects of different lime levels on the composition of alfalfa tops, experiment 3, Fayetteville, Ark.*

Soil	$CaCO_3$	Plant composition [1]									
		K	Ca	P	Mg	B	Mn	Al	Na	Fe	Cu
	T./acre	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m*
Bayboro	0	3. 3	1. 6	0. 20	0. 88	100	220	230	160	190	3. 2
	1	2. 8	2. 5	. 20	. 71	110	210	380	290	300	5. 9
	2	3. 4	3. 0	. 26	. 61	120	160	310	300	250	3. 0
	3	3. 0	3. 4	. 26	. 54	98	170	320	320	210	4. 0
	4	3. 5	3. 2	. 24	. 49	120	140	350	230	260	2. 4
	6	3. 1	3. 6	. 28	. 37	65	140	330	270	185	3. 7
	8	3. 2	3. 9	. 26	. 32	54	120	290	120	160	2. 6
Bladen	[2] 0	----	----	----	----	----	----	----	----	----	----
	1	4. 0	1. 8	. 22	. 39	100	110	200	130	440	4. 3
	2	3. 8	2. 6	. 20	. 30	100	110	250	270	180	3. 7
	3	3. 8	3. 2	. 24	. 27	120	110	310	200	260	2. 6
	4	3. 1	3. 6	. 26	. 24	94	100	300	180	220	2. 6
	6	3. 4	6. 6	. 33	. 26	61	120	270	150	180	3. 7
	8	2. 8	7. 3	. 28	. 18	45	220	180	120	130	2. 4
Leon	[2] 0	----	----	----	----	----	----	----	----	----	----
	1	5. 1	1. 1	. 94	. 49	>340	210	360	160	310	2. 4
	2	3. 6	2. 4	. 56	. 24	>340	110	190	160	170	3. 0
	3	3. 2	2. 8	. 36	. 20	270	110	190	66	150	9. 0
	4	3. 2	3. 4	. 33	. 17	200	92	180	120	140	2. 4
	6	3. 4	6. 6	. 33	. 23	>340	110	200	58	120	2. 8
	8	3. 2	4. 6	. 33	. 18	200	80	140	41	100	2. 8
Vaiden	0	3. 5	3. 4	. 22	. 14	80	150	200	50	160	7. 6
	1	3. 3	2. 8	. 26	. 14	45	140	310	80	290	12. 0
	2	3. 3	3. 9	. 26	. 15	40	140	270	90	240	7. 6
	3	3. 8	3. 4	. 22	. 13	29	110	240	90	150	6. 4
	4	3. 9	4. 6	. 26	. 14	23	130	350	80	240	5. 6
	6	3. 6	4. 6	. 26	. 17	26	130	210	66	170	5. 9
	8	3. 0	5. 9	. 28	. 14	26	150	320	130	260	5. 3

[1] Values are averages of three replications.
[2] Plants died.

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TABLE 11.—*Effects of lime rate on alfalfa yields and soil properties, experiment 4, Fayetteville, Ark.*

Soil	$CaCO_3$	pH [3]	Alfalfa value yield [1]	Extractable aluminum [2] by: NH_4OAc method		Extractable aluminum [2] by: KCl method		Exchangeable Mn [3]
				Meq./100 g.	Pct of CEC [4]	Meq./100 g.	Pct. of CEC [4]	
	T./acre		*G./pot*					*P.p.m.*
Decatur	0	5.5	5.49	1.36	11.6	0.05	0.4	136.0
	1	6.2	5.61	1.21	10.3	.03	.3	98.0
	2	6.7	6.22	1.07	9.1	.03	.3	71.0
	3	7.1	5.92	.89	7.6	.03	.3	30.0
	4	7.2	6.69	1.20	10.2	.03	.3	24.0
	6	7.4	6.97	.97	8.3	.03	.3	18.0
Rains	0	4.6	2.77	1.02	30.0	.41	12.0	4.9
	1	5.5	7.62	.72	21.2	.04	1.1	1.7
	2	6.4	4.65	.49	14.4	.05	1.4	2.5
	3	7.2	2.60	.81	23.8	.04	1.1	2.7
	4	7.4	3.64	.81	23.8	.05	1.5	3.9
	6	7.5	3.57	.52	15.3	.06	1.5	2.0
Tifton	0	5.5	3.08	1.08	27.0	.06	1.4	23.0
	1	6.0	6.82	.69	17.2	.05	1.3	13.6
	2	6.7	7.02	.85	21.2	.02	.6	14.0
	3	7.3	8.11	.57	14.2	.03	.8	9.5
	4	7.6	7.32	.60	15.0	.02	.4	7.0
	6	7.6	6.51	.65	16.2	.02	.5	5.0

[1] Total of three cuttings—average of three replications. On Decatur soil the *F* value for lime treatments was not statistically significant. On Rains and Tifton soils, for comparing yield at any lime level within a soil, the difference required for significance at the 5-percent level by *t*-test (L.s.d.) is 1.81 g./pot.

[2] NH_4OAc at pH 4.8 and 1 *N* KCl at pH 7.0.

[3] Extracted with 1 *N* NH_4OAc at pH 7.0.

[4] Cation-exchange-capacity by NH_4OAc method.

TABLE 12.—*Effects of different lime levels on the composition of alfalfa tops, experiment 4, Fayetteville, Ark.*

Soil	$CaCO_3$	Plant composition [1]: K	Ca	P	Mg	B	Mn	Al	Na	Fe	Cu
	T./acre	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*
Decatur	0	4.1	1.80	0.26	0.20	50	190	98	90	80	8.6
	1	3.5	1.60	.22	.17	54	130	88	90	90	8.0
	2	3.7	1.90	.26	.17	54	130	92	58	86	7.2
	3	3.1	1.90	.28	.16	47	110	82	90	76	6.4
	4	2.8	2.00	.24	.16	28	92	76	80	64	7.2
	6	3.1	2.30	.30	.17	37	120	84	50	72	6.8
Rains	0	4.4	.77	.26	.44	130	280	78	90	90	12.0
	1	4.3	1.40	.28	.19	69	68	76	66	96	11.0
	2	4.2	2.00	.33	.19	110	58	82	45	100	13.0
	3	4.8	1.70	.30	.16	69	58	78	110	86	8.6
	4	5.0	1.90	.30	.17	80	68	92	72	100	7.6
	6	5.0	2.00	.36	.17	110	54	78	58	86	11.0
Tifton	0	4.8	.90	.22	.37	130	420	68	37	54	13.0
	1	4.3	1.30	.26	.20	58	86	78	37	80	12.0
	2	3.5	1.40	.24	.14	45	62	70	24	86	10.0
	3	4.0	2.00	.30	.17	37	74	84	41	76	11.0
	4	4.3	1.80	.30	.16	37	74	76	27	64	9.2
	6	3.9	1.70	.28	.16	47	62	70	30	61	8.0

[1] Values are averages of three replications.

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